

## CLAIMS

1. A probe for use in a scanning probe microscope, comprising a single conductive material having a sharp end.

2. The probe as set forth in claim 1, wherein said single conductive material comprises one of W, Pt/Ir, Ni, Au and Ag.

3. A probe for use in a scanning probe microscope, comprising a single conductive wire having a sharp end.

4. The probe as set forth in claim 3, wherein said single conductive wire comprises one of W, Pt/Ir, Ni, Au and Ag.

5. A scanning probe microscope for a sample, comprising:

a probe having a body and a sharp end, said body and said sharp end including a single conductive material; and

a vibrating unit, provided at said body, for vibrating said sharp end along a direction approximately in parallel with a surface of said sample.

6. The scanning probe microscope as set forth in claim 5, wherein said single conductive material comprises one of W, Pt/Ir, Ni, Au and Ag.

7. The scanning probe microscope as set forth in claim 5, wherein said single conductive material comprises a wire.

8. The scanning probe microscope as set forth in claim 5, wherein said vibrating unit comprises a piezoelectric element.

9. The scanning probe microscope as set forth in claim 8, wherein said probe is electrically-isolated from said piezoelectric element.

10. The scanning probe microscope as set forth in claim 5, wherein said probe is vibrated at a resonance

frequency of said probe.

11. The scanning probe microscope as set forth in claim 8, wherein said probe is vibrated at a resonance frequency of said piezoelectric element.

5 12. The scanning probe microscope as set forth in claim 8, further comprising a detector, provided in a part of said piezoelectric element, for detecting a vibration state of said probe.

10 13. The scanning probe microscope as set forth in claim 12, further comprising a feedback control unit, connected to said detector, for performing a feedback control operation upon a distance between said the sharp end of said probe and said sample in accordance with the detected vibration state of said detector, so that the  
15 detected vibration state is brought close to a predetermined definite value.

14. A scanning probe microscope for a sample, comprising:

a probe having a conductive sharp end;

20 a moving unit for moving said sample along a Z-direction and moving said sample in X-and Y-directions;

a vibrating unit for vibrating said probe along a direction approximately in parallel with a surface  
25 of said sample;

a vibration detecting unit for detecting a vibration state of said probe;

30 a signal detecting unit for detecting an electrical characteristic signal between said probe and said sample;

a control unit for controlling an interaction between said probe and said sample so that the interaction is brought close to a predetermined definite level; and

35 a voltage applying unit for applying an AC/DC voltage to said sample.

15. The scanning probe microscope as set forth in claim 14, wherein said control unit comprises a feedback control unit for adjusting a distance between the sharp and of said probe and said sample so that the detected vibration state of said probe is brought close to a predetermined definite level.

16. The scanning probe microscope as set forth in claim 14, wherein the detected vibration state of said probe is one of a resonance amplitude and a resonance frequency of said probe.

17. The scanning probe microscope as set forth in claim 14, wherein the detected vibration state of said probe is one of a resonance amplitude and a resonance frequency of said vibrating unit.

18. The scanning probe microscope as set forth in claim 14, wherein the detected vibration state of said probe is a signal relating to a Q-value of vibration of said probe.

19. The scanning probe microscope as set forth in claim 14, wherein said control unit comprises a feedback control unit for adjusting a distance between the sharp and of said probe and said sample so that the detected electrical characteristic signal is brought close to a predetermined definite level.

20. The scanning probe microscope as set forth in claim 14, wherein said signal detecting unit comprises;  
a detector for detecting a signal from said probe;

a diode detector, connected to said detector, for detecting an output signal of said detector; and

a frequency detector, connected to said diode detector, for detecting an output signal of said diode detector by using a frequency close to a vibration frequency of said probe as a reference.

21. The scanning probe microscope as set forth in

claim 14, wherein said signal detecting unit comprises;  
a detector for detecting a signal from said probe;

5 a diode detector, connected to said detector,  
for detecting an output signal of said detector; and  
a frequency detector, connected to said diode detector, for detecting an output signal of said diode detector by using a frequency close to a frequency of said AC/DC voltage as a reference.

10 22. The scanning probe microscope as set forth in claim 14, wherein said signal detecting unit comprises;  
a detector for detecting a signal from said probe;

15 a diode detector, connected to said detector, for detecting an output signal of said detector;  
a first frequency detector, connected to said diode detector, for detecting an output signal of said diode detector by using a frequency close to a frequency of said AC/DC voltage as a reference; and

20 a second frequency detector, connected to said diode detector, for detecting an output signal of said diode detector by using a frequency close to a frequency of said AC/DC voltage as a reference.

25 23. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a capacitance between said probe and said sample.

30 24. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a differential component of a capacitance between said probe and said sample with respect to an AC component of said AC/DC voltage.

35 25. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a differential component of a capacitance between said probe and said sample with respect to a vibration

coordinate of said probe.

26. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a second-order differential component of a capacitance between said probe and said sample with respect to an AC component of said AC/DC voltage and a vibration coordinate of said probe.

27. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a current flowing through said probe and said sample.

28. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a differential component of a current flowing through said probe and said sample with respect to an AC component of said AC/DC voltage.

29. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a differential component of a current flowing through said probe and said sample with respect to a vibration coordinate of said probe.

30. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal shows a second-order differential component of a current flowing through said probe and said sample with respect to an AC component of said AC/DC voltage and a vibration coordinate of said probe.

31. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal is detected under a condition that said probe and said sample are incorporated into a vacuum chamber.

32. The scanning probe microscope as set forth in claim 14, wherein said electrical characteristic signal is detected under a condition that a temperature of said probe and said sample is being changed.

33. The scanning probe microscope as set forth in claim 15, further comprising a display unit for displaying a surface information of said sample in accordance with the adjusted distance.

5 34. The scanning probe microscope as set forth in claim 19, further comprising a display unit for displaying the detected electrical characteristic signal.

10 35. The scanning probe microscope as set forth in claim 14, wherein a frequency of an AC component of said AC/DC voltage is higher than a frequency of the vibration state of said probe.

36. A scanning probe microscope for a sample, comprising:

a conductive probe;

15 a control unit for controlling a relative location of said probe to said sample;

a voltage applying unit for applying a voltage between said probe and said sample;

20 a capacitance detecting unit for detecting a capacitance information between said probe and said sample;

a calculating unit for calculating a first differential component of said capacitance information with respect to said voltage;

25 a calculating unit for calculating a second differential component of said capacitance information with respect to a coordinate; and

30 a calculating unit for calculating a ratio of said second differential component to said first differential component.

37. The scanning probe microscope as set forth in claim 36, further comprising a calculating unit for calculating an integration value of said ratio with respect to said coordinate.

35 38. The scanning probe scanning microscope as set

forth in claim 36, wherein said coordinate is in parallel with a surface of said sample,

said microscope further comprising a vibrating unit for vibrating said conductive probe along said coordinate, so that the second differential component of said capacitance information is a component of said capacitance information changing at a vibration frequency of said conductive probe.

39. The scanning probe microscope as set forth in claim 36, further comprising a calculating unit for converting said ratio into information regarding a concentration of majority carriers in equilibrium of said sample.

40. The scanning probe microscope as set forth in claim 39, further comprising a display unit for displaying said majority carrier concentration information.

41. The scanning probe scanning microscope as set forth in claim 36, further comprising a calculating unit for converting said ratio into information regarding a concentration of ionized dopants of said sample.

42. The scanning probe microscope as set forth in claim 41, further comprising a display unit for displaying said ionized dopant concentration information.

43. A method for controlling a scanning probe microscope for a sample, comprising: a probe having a conductive sharp end; a moving unit for moving said sample along a Z-direction and moving said sample in X- and Y-directions; a vibrating unit for vibrating said probe along a direction approximately in parallel with a surface of said sample; a vibration detecting unit for detecting a vibration state of said probe; a signal detecting unit for detecting an electrical characteristic signal between said probe and said sample; a control unit for controlling an interaction between said probe and said sample so that the interaction is brought close to a predetermined definite

level; and a voltage applying unit for applying an AC/DC voltage to said sample,

said method comprising a step of adjusting a distance between the sharp end of said probe and said sample so that the detected vibration state of said probe is brought close to a predetermined definite level.

44. A method for controlling a scanning probe microscope for a sample, comprising: a probe having a conductive sharp end; a moving unit for moving said sample along a Z-direction and moving said sample in X- and Y-directions; a vibrating unit for vibrating said probe along a direction approximately in parallel with a surface of said sample; a vibration detecting unit for detecting a vibration state of said probe; a signal detecting unit for detecting an electrical characteristic signal between said probe and said sample; a control unit for controlling an interaction between said probe and said sample so that the interaction is brought close to a predetermined definite level; and a voltage applying unit for applying an AC/DC voltage to said sample,

said method comprising a step of adjusting a distance between the sharp end of said probe and said sample so that the detected electrical characteristic signal is brought close to a predetermined definite level.

45. The method as set forth in claim 44, further comprising the steps of:

detecting a signal from said probe by a detector diode-detecting an output signal of said detector by a diode; and

detecting an output signal of said diode by using a frequency close to a vibration frequency of said probe as a reference.

46. The method as set forth in claim 44, further comprising the steps of:

detecting a signal from said probe by a



detector;

detecting an output signal of said detector by a diode; and

5 detecting an output signal of said diode by using a frequency close to a frequency of an AC component of said AC/DC voltage as a reference.

47. The method as set forth in claim 44, further comprising the steps of:

10 detecting a signal from said probe by a detector;

detecting an output signal of said detector by a diode; and

15 detecting an output signal of said diode by using a frequency close to a frequency of an AC component of said AC/DC voltage as a reference and by using a frequency close to a vibration frequency of said probe as a reference.

20 48. The method as set forth in claim 44, wherein said electrical characteristic signal is detected under a condition that said probe and said sample are incorporated into a vacuum chamber.

25 49. The method as set forth in claim 44, wherein said electrical characteristic signal is detected under a condition that a temperature of said probe and said sample is being changed.

50. The method as set forth in claim 43, wherein a frequency of the vibration state of said probe is lower than a frequency of an AC component of said AC/DC voltage.

30 51. The method as set forth in claim 44, wherein a frequency of the vibration state of said probe is lower than a frequency of an AC component of said AC/DC voltage.

52. A scanning probe microscope for a sample, comprising:

35 a moving unit for moving said sample in X-, Y- and Z-directions;

a conductive probe approximately perpendicular to a surface of said sample and having a sharp end capable of being in proximity to the surface of said sample;

an oscillator;  
a vibrating unit, connected to said oscillator, for vibrating said conductive probe in the X-direction in accordance with a frequency of said oscillator;

a vibration detecting unit for detecting a vibration amplitude of said conductive probe to generate a vibration voltage; and

a feedback control unit, connected between said vibration detecting unit and said moving unit, for controlling a location of said sample in the Z-direction in accordance with the detected vibration amplitude of said vibration detecting unit, so that the vibration amplitude of said vibrating detecting unit is brought close to a predetermined definite value.

53. The scanning probe microscope as set forth in claim 52, wherein said vibration detecting unit comprises a first lock-in amplifier for detecting a vibration frequency of said conductive probe using the frequency of said oscillator to generate a difference in phase between the vibration frequency of said conductive probe and the frequency of said oscillator as the detected vibration amplitude,

said feedback control unit comprising a servo circuit, connected to said first lock-in amplifier, for controlling the location of said sample in the Z-direction so that said difference in phase is brought close to a predetermined definite value.

54. The scanning probe microscope as set forth in claim 52, further comprising a first display unit, for displaying the location of said sample in the Z-direction while a predetermined area of said sample in the X- and

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59. The scanning probe microscope as set forth in claim 58, further comprising a third display unit for displaying the differential component of the capacitance signal of said capacitance sensor with respect to said AC/DC modulation voltage while a predetermined area of said sample in the X- and Y-directions is scanned by said conductive probe using said moving unit.

60. The scanning probe microscope as set forth in claim 56, further comprising a third lock-in amplifier,

connected to said capacitance sensor, for detecting a differential component of a capacitance signal of said capacitance sensor with respect to a vibration direction of said conductive probe using a frequency of said oscillator as a reference.

61. The scanning probe microscope as set forth in claim 60, further comprising a fourth display unit for displaying the differential component of the capacitance signal of said capacitance sensor with respect to the vibration direction of said conductive probe while a predetermined area of said sample in the X- and Y- directions is scanned by said conductive probe using said moving unit.

62. The scanning probe microscope as set forth in claim 60, further comprising a fourth lock-in amplifier, connected to said third lock-in amplifier, for detecting a second-order differential component of the capacitance signal of said capacitance sensor with respect to the vibration direction of said conductive probe and said AC/DC voltage by said AC/DC modulation voltage using a frequency thereof as a reference.

63. The scanning probe microscope as set forth in claim 62, further comprising a fifth display unit for displaying the second-order differential component of the capacitance signal of said capacitance sensor while a predetermined area of said sample in the X- and Y- directions is scanned by said conductive probe using said moving unit.

64. The scanning probe microscope as set forth in claim 56, further comprising:

a second lock-in amplifier, connected to said capacitance sensor, for detecting a first differential component of a capacitance signal of said capacitance sensor with respect to said AC/DC modulation voltage using a frequency thereof as a reference;

a third lock-in amplifier, connected to said capacitance sensor, for detecting a second differential component of a capacitance signal of said capacitance sensor with respect to a vibration direction of said  
 5 conductive probe using a frequency of said oscillator as a reference;

a computer, connected to said first and second lock-in amplifiers, for calculating a ratio of said second differential component to said first differential  
 10 component; and

a sixth display unit for displaying information relating to said ratio while a predetermined area of said sample in the X-and Y-directions is scanned by said conductive probe using said moving unit.

65. The scanning probe microscope as set forth in claim 56, further comprising:

a second lock-in amplifier, connected to said capacitance sensor, for detecting a first differential component of a capacitance signal of said capacitance sensor with respect to said AC/DC modulation voltage using a frequency thereof as a reference;

a third lock-in amplifier, connected to said capacitance sensor, for detecting a second differential component of a capacitance signal of said capacitance sensor with respect to a vibration direction of said  
 25 conductive probe using a frequency of said oscillator as a reference;

a computer, connected to second and third lock-in amplifiers, for calculating a ratio of said second differential component to said first differential component and calculating an integration value of said ratio in the  
 30 X-direction,

a sixth display unit for displaying said integration value while a predetermined area of said  
 35 sample in the X-and Y-directions is scanned by said

conductive probe using said moving unit.

66. The scanning probe microscope as set forth in claim 55, wherein said sensor comprises a current sensor.

67. The scanning probe microscope as set forth in claim 66, further comprising a sixth display unit for displaying a current signal of said current sensor while a predetermined area of said sample in the X- and Y-directions is scanned by said conductive probe using said moving unit.

68. The scanning probe microscope as set forth in claim 66, further comprising a fifth lock-in amplifier, connected to said current sensor, for detecting a differential component of a current signal of said current sensor with respect to a voltage of said AC/DC modulation voltage using a frequency thereof as a reference.

69. The scanning probe microscope as set forth in claim 68, further comprising an eighth display unit for displaying the differential component of the current signal of said current sensor with respect to said AC/DC modulation voltage while a predetermined area of said sample in the X- and Y-directions is scanned by said conductive probe using said moving unit.

70. The scanning probe microscope as set forth in claim 66, further comprising a sixth lock-in amplifier, connected to said current sensor, for detecting a differential component of a current signal of said current sensor with respect to a vibration direction of said conductive probe using a frequency of said oscillator as a reference.

71. The scanning probe microscope as set forth in claim 70, further comprising a ninth display unit for displaying the differential component of the current signal of said current sensor with respect to the vibration direction of said conductive probe while a predetermined area of said sample in the X- and Y-directions is scanned

by said conductive probe using said moving unit.

72. The scanning probe microscope as set forth in claim 70, further comprising a seventh lock-in amplifier, connected to said sixth lock-in amplifier, for detecting a second-order differential component of the current signal of said current sensor with respect to the vibration direction of said conductive probe and said AC/DC voltage by a frequency of said oscillator as a reference and said AC/DC modulation voltage using a frequency thereof as a reference.

73. The scanning probe microscope as set forth in claim 72, further comprising a tenth display unit for displaying the second-order differential component of the current signal of said current sensor while a predetermined area of said sample in the X- and Y- directions is scanned by said conductive probe using said moving unit.

74. The scanning probe microscope as set forth in claim 55, wherein a frequency of said AC/DC modulation voltage is higher than a frequency of the vibrating unit.

75. The scanning probe microscope as set forth in claim 64, wherein said ratio shows information regarding a slope of a concentration of majority carriers in equilibrium with respect to said vibration direction when said AC/DC modulation voltage is small so as not to generate an inversion region in said sample.

76. The scanning probe microscope as set forth in claim 64, wherein said ratio shows information regarding a slope of a concentration of ionized dopants with respect to said vibration direction when said AC/DC modulation voltage is large so as to generate an inversion region in said sample.

77. The scanning probe microscope as set forth in claim 65, wherein said integration value shows information regarding a logarithmic value of a

concentration of majority carriers in equilibrium with respect to said vibration direction when said voltage is small so as not to generate an inversion region in said sample.

- 5        78.    The scanning probe microscope as set forth in claim 65, wherein said integration shows information regarding a logarithmic value of a concentration of ionized dopants with respect to said vibration direction when said voltage is large so as to generate an inversion region in
- 10    said sample.

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